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THE EFFECT OF DECREASED BAROMETRIC PRESSURE ON OXYGEN CONSUMPTION

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School of Aerospace Medicine
Aerospace Medical Division (AFSC)
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FOREWORD

This report was prepared by the following personnel in the Physiology Branch:

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ABSTRACT

There have been conflicting reports in the literature concerning the effect of decreased barometric pressure on oxygen consumption, some reports citing a decrease in consumption and others citing no change in consumption. The resting oxygen consumption of 8 healthy men was measured at ground level, at 18,000 feet pressure altitude, and at 30,000 feet pressure altitude. There was no change in oxygen consumption with change in pressure altitude. The findings were discussed from three aspects: (1) the work of breathing at low barometric pressures; (2) the methodology for measuring oxygen consumption; and (3) a possible decreased nitrogen effect.

This technical documentary report has been reviewed and is approved.

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THE EFFECT OF DECREASED BAROMETRIC PRESSURE ON OXYGEN CONSUMPTION

1. INTRODUCTION

There have been conflicting reports in the literature concerning the effect of decreased barometric pressure on resting oxygen consumption. Some studies report no change in consumption, others report a decrease, but none report an increase in consumption. For example, Boothby et al. (1) in 1940 and Houston and Riley (2) in 1947 reported no effect of altitude on oxygen consumption at rest. On the other hand, Cook (3) in 1945 and Berg and Cook (4) in 1946 reported a decrease in oxygen consumption due to decreased barometric pressure.

With the advent of sealed cabin atmospheres for space flight, the effect of decreased barometric pressure on oxygen consumption becomes important. Since weight restrictions limit the stressing of such cabins, the cabins will likely be maintained at less than a full atmosphere of pressure.

The gaseous environment of a space cabin must, of course, provide a physiologic atmosphere for its occupants. Thus, if the total cabin pressure is reduced below normal, the percentage of oxygen must be increased to prevent the alveolar oxygen tension from falling to hypoxic levels. Oxygen stores must be provided to replenish the oxygen used from this environment.

To plan for these stores, it is important to determine the effect of decreased barometric pressure on oxygen consumption. Furthermore, if the resting oxygen consumption is actually decreased at low barometric pressure, the physiologic implications should be considered.

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In this work, resting oxygen consumption has been measured at three different barometric pressures: ground level, 18,000 feet pressure altitude, and 30,000 feet pressure altitude. Each of these could be a practical pressure altitude for a space cabin. One hundred percent oxygen was used to determine oxygen consumption at each altitude, so that hypoxia would not be a factor.

2. METHODS

Eight men from the laboratory were used as subjects. They were either altitude chamber technicians or flight surgeons who were accustomed to the environment in which they were tested. Each subject reported for the experiment during normal duty hours and was tested in a resting, not a basal, state. All subjects were tested while comfortably seated in an altitude chamber (fig. 1). At ground level (approximately 747 mm. Hg), before the oxygen consumption runs were begun, the subject breathed 100 percent oxygen for 7 minutes, by mask, to accomplish nitrogen washout. After denitrogenation, the subject took a deep breath of oxygen and held his breath while a clip was put on his nose and the mouthpiece of the spirometer was adjusted in his mouth.

The subject then breathed 100 percent oxygen from a 13½-liter spirometer equipped with a CO_2 absorber and appropriate low-resistance, one-way valves. When the subject had settled down to a regular, quiet breathing pattern, an 8-minute oxygen consumption run was performed. Ground level barometric pressure and spirometer temperature taken near the inlet to the inhalation hose were recorded. After this, he took a deep breath of oxygen and held his breath. The nose clip was removed and he transferred to his oxygen mask and breathed 100 percent oxygen from an oxygen regulator.

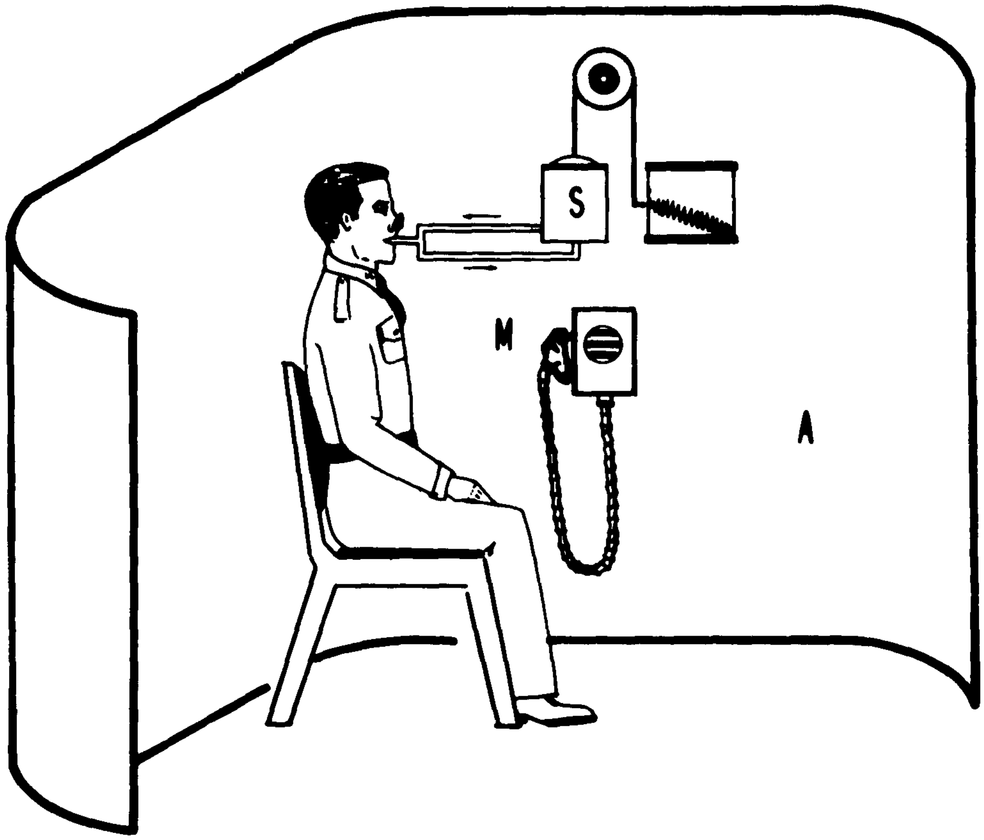

FIGURE 1

Experimental setup. S, Spirometer; M, oxygen mask; A, wall of altitude chamber.

The subject remained seated, breathing 100 percent oxygen, while the pressure in the altitude chamber was lowered to 380 mm. Hg, the pressure equivalent of 18,000 feet. The oxygen mask was then removed, the nose clip replaced, and the spirometer mouthpiece adjusted into position. Again, after a period of quiet breathing, an 8-minute oxygen consumption run was performed at this barometric pressure. The temperature of the spirometer was recorded. The entire procedure was repeated at 30,000 feet pressure altitude (225 mm. Hg).

After the measurements at 225 mm. Hg were completed, the pressure in the altitude chamber was returned to ground level.

Figure 2 is a spirogram showing oxygen consumption runs at the three altitudes tested. The lower tracing was done at ground level, the middle tracing at 18,000 feet pressure altitude, and the upper tracing at 30,000 feet pressure altitude.

For each barometric pressure at which determinations were made, oxygen consumption in cubic centimeters per minute, ATPS, taken from the spirogram, was converted to oxygen consumption in cubic centimeters per minute, STPD, by the relationship:

$$\text{Vol}_{\text{STPD}} = \text{Vol}_{\text{ATPS}} \times \frac{P_{\text{amb}} - P_{H_2O}}{760} \times \frac{273}{273 + T_{\text{spirometer}}}$$

During the tests, ambient temperature in the chamber remained constant and the spirometer temperature varied by no more than 0.5 C.

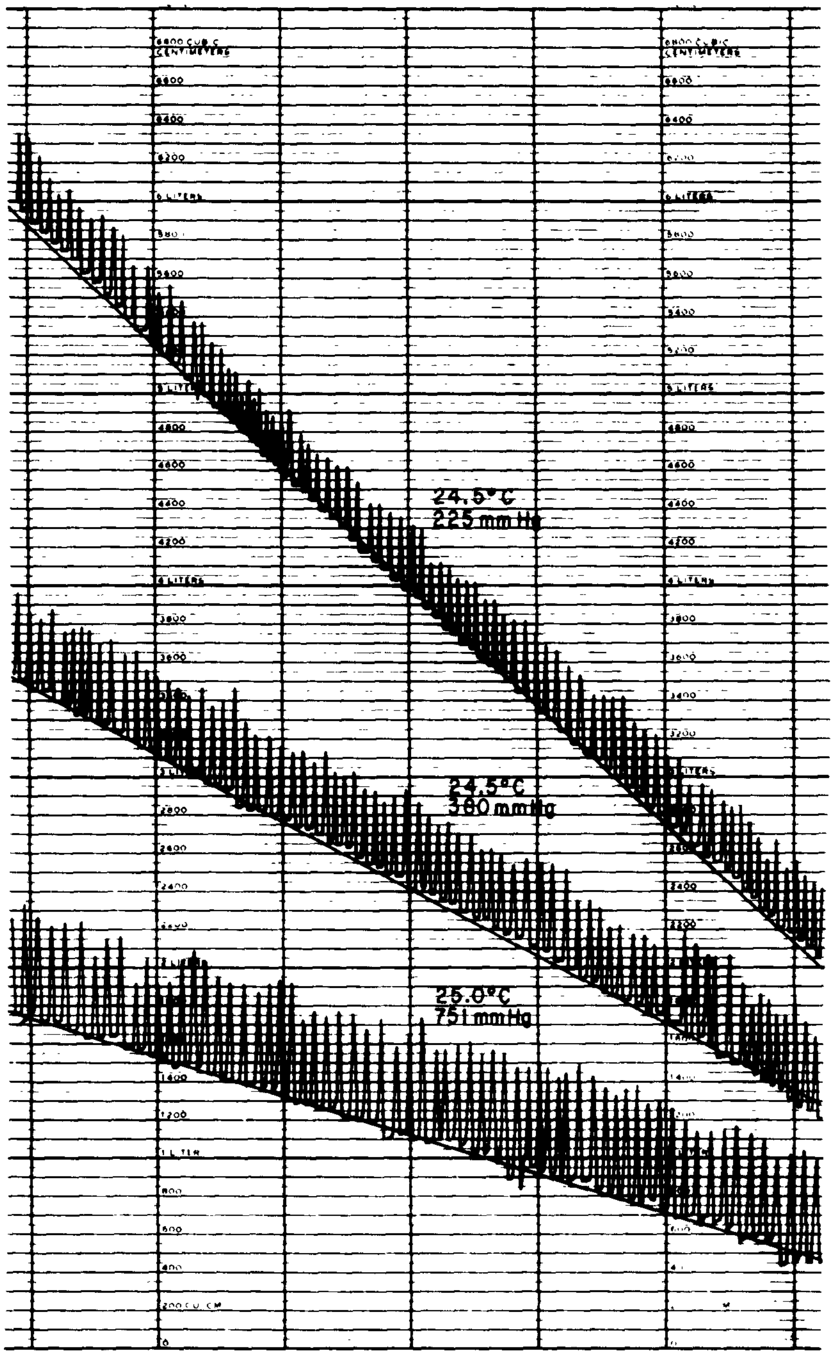

FIGURE 2

Spirogram showing oxygen consumption slopes at various barometric pressures. Temperatures shown with pressures are spirometer temperatures.

TABLE I

Resting oxygen consumption of each subject at each barometric pressure

Subject	Height (in.)	Weight (lb.)	Estimated body surface area ($m.^2$)	O_2 consumption, cc./min. STPD		
				Ground level (747 mm. Hg)	18,000 ft. (380 mm. Hg)	30,000 ft. (225 mm. Hg)
P.E.	74	187	2.12	324 (153)*	286 (135)*	293 (138)*
D.H.	67	138	1.72	227 (132)	213 (124)	218 (127)
L.J.	70	163	1.92	314 (164)	307 (160)	338 (176)
S.K.	71	152	1.88	261 (139)	225 (120)	218 (116)
L.K.	72	230	2.26	281 (124)	329 (146)	329 (146)
R.M.	71	170	1.97	325 (165)	262 (133)	262 (133)
F.M.	68	150	1.80	235 (131)	241 (134)	233 (129)
J.S.	72	194	2.10	255 (121)	260 (124)	246 (117)
Mean	—	—	—	278 (141)	265 (134)	267 (135)

*Cubic centimeters per minute per square meter.

3. RESULTS

The oxygen consumption of each subject at each barometric pressure considered is shown in table I. The variation found from subject to subject at different altitudes is within the normal range of variation usually found at ground level. At 380 mm. Hg ambient pressure, 5 of the 8 subjects showed a decrease in oxygen consumption from ground level values and 3 subjects showed an increase. At 225 mm. Hg ambient pressure, 6 of the 8 subjects showed a decrease in oxygen consumption from ground level values and 2 subjects showed an increase.

While decreases in oxygen consumption outnumber the increases, a statistical analysis of the data, shown in table II, failed to show any significant differences which could be attributed to the decrease in barometric pressure. This analysis gave a 95 percent confidence level for the difference between the control (ground level) and 30,000 feet of from 0 to 9.08 cc./min./$m.^2$ The 95 percent confidence level for 18,000 feet would be almost identical. The variance ratio (F) was 0.99; the .05 level of significance would require a variance ratio of 3.74.

4. DISCUSSION

Boothby et al. (1), Houston and Riley (2), and the present results all failed to find any evidence for a decrease in oxygen consumption with a decrease in barometric pressure. Cook (3) and Berg and Cook (4), on the other hand, have reported decreases in mean oxygen consumption ranging up to 24 percent in their

TABLE II

Analysis of variance of resting O_2 consumption at ground level, 18,000 feet, and 30,000 feet*

Source	df	SS	MS	F	P
Subjects	7	4446.96	635.14	5.96	<.005
Altitude	2	210.58	105.29	.99	NS
Subjects x Altitude	14	1491.42	106.53		
Total	23	6148.96			

Standard error of difference between treatment means $\left(\frac{2\ MS}{8}\right)^{1/2} = \left(\frac{2 \times 106.53}{8}\right)^{1/2} = 5.16.$

*Cubic centimeters per minute per square meter.

test subjects. These divergent findings may be considered from several different aspects. We shall consider the work of breathing at low barometric pressures, the methodology for measuring oxygen consumption, and a possible decreased nitrogen effect.

Work of breathing

The work of breathing at decreased barometric pressure should be less than at ground level. Since the work of breathing can be expressed in terms of oxygen consumption, the oxygen consumption should also be less at decreased barometric pressure. The work necessary to stretch the lungs and thorax would presumably remain the same as at ground level, but the work necessary to move the air in and out of the lungs and respiratory passages decreases. Resistance to flow of respiratory gases is less because of lowered density at decreased barometric pressure (5). This decrease of resistance, however, would be such a small part of the total work of breathing under resting conditions that it would be difficult to measure.

Methodology

Oxygen consumption may be measured by three general methods:

A. Oxygen consumption may be measured from a spirometer or other container in a fixed period of time. As long as pressure, temperature, and humidity effects are considered and the minute consumption is converted to STPD, this is a very feasible method. This method was used in this study and no change in oxygen consumption associated with decrease in barometric pressure was noted. It was used also by Boothby et al. (1) and by Houston and Riley (2), who likewise reported no change in O_2 consumption. However, Cook (3), using this method, reported a significant decrease in oxygen consumption with reduced barometric pressure.

B. Exhaled gas may be collected for a fixed period of time and then analyzed for oxygen and carbon dioxide, the inhaled gas mixture being known and the respiratory quotient estimated. Pressure, temperature, and humidity must again be considered in converting the minute oxygen consumption to STPD. Houston and Riley (2), using this method, reported no change in resting oxygen consumption associated with decreased barometric pressure. On the other hand, Berg and Cook (4), using this method, reported a decrease in oxygen consumption with a decrease in barometric pressure.

C. Expired air may be analyzed continuously and its output measured in a fixed period of time. This is a somewhat more complicated method, but if the equipment is properly calibrated it is very satisfactory. Berg and Cook (4), using this method, reported a decrease in oxygen consumption with decreased barometric pressure.

If decrease in oxygen consumption with decreased barometric pressure actually occurred, one would expect the decrease to show up by any method used. On this point there is no accord, because Cook, using method A (3), and Berg and Cook, using methods B and C (4), have reported a decrease in oxygen consumption, while Boothby et al. (1) and the present study, using method A, and Houston and Riley (2), using methods A and B, have shown no decrease in oxygen consumption.

Decreased nitrogen effect

Cook (6) has recently discussed the physiologic effects of inert gases and states that "the reduction of metabolism consequent to reduction of total pressure, suggests that the metabolism of the intact organism is stabilized by opposing forces, nitrogen tending to depress it and the total pressure tending to increase it."

As we have seen, our own data fail to support Cook's contention that metabolism is reduced with reduced barometric pressure. While the subjects used in these experiments were partially denitrogenated, tissue nitrogen concentration was probably decreasing continuously during the course of the measurements. Therefore, according to Cook's hypothesis, it may be argued that no change in

oxygen consumption was noted because the lowered nitrogen tension nullified any effect of decreased barometric pressure.

While there has been ample demonstration of the narcotic effect of high pressures of nitrogen, metabolic effects attributable to low nitrogen pressure are not well documented.

Several arguments weigh against any important effect of low nitrogen tension on oxygen consumption. The narcotic action appears to reach asymptotic levels at about 1.5 or 2.0 atmospheres of nitrogen pressure where a prolonged time is required to block alpha waves of the EEG in man (7). Further, such narcotic action appears to interfere physically with nerve cell permeability and electrical polarization. Such interference would presumably have only a minor direct influence on oxygen consumption because of the low contribution of nerve to total energy production; however, such interference might have a large indirect influence on oxygen consumption if depression of the nervous system caused general metabolism also to be reduced.

The present experiments indicate that there is no effect of reduced barometric pressure on oxygen consumption. However, since the question of the effect of decreased nitrogen tension on oxygen consumption has been raised and is unanswered, further experiments are planned in order to study this effect independently.

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2. Oxygen consumption
3. Barometric pressure

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